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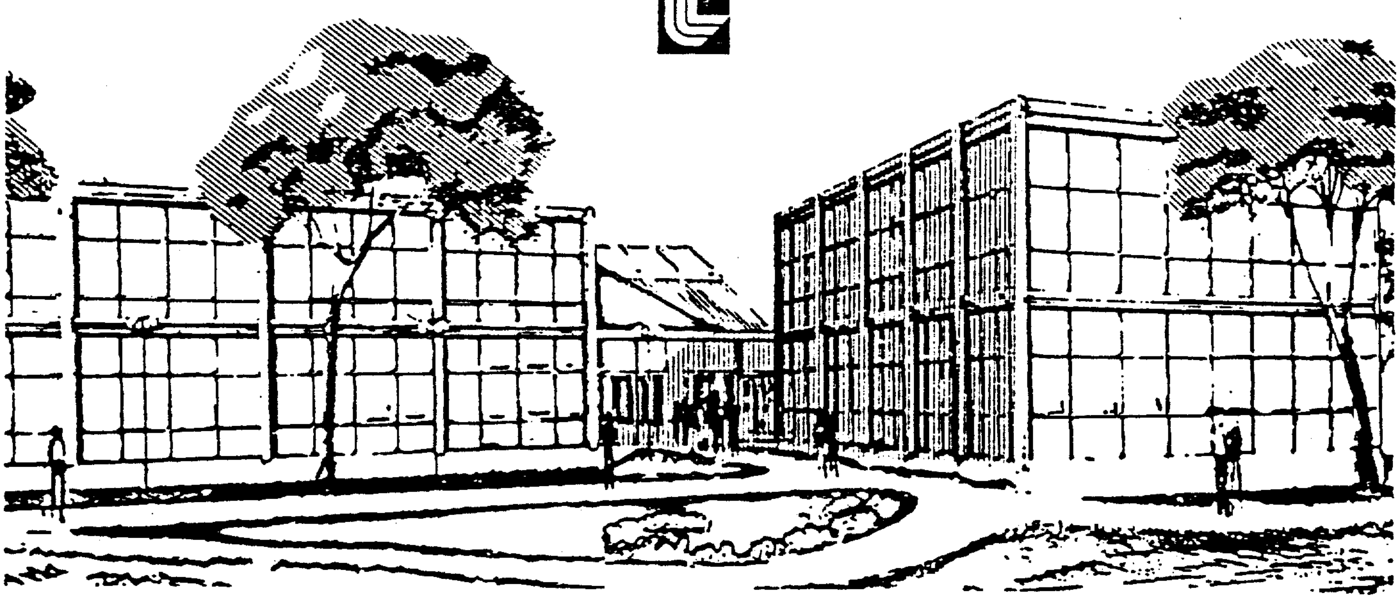

1064 - NM LASER DAMAGE THRESHOLDS OF POLISHED GLASS SURFACES AS A FUNCTION OF PULSE DURATION AND SURFACE ROUGHNESS*

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Laser damage thresholds were measured for four polished glass surfaces, using linearly polarized 1064-nm pulses with durations of 0.17 ns, 1.0 ns, 1.6 ns, and 3.2 ns. Thresholds scaled approximately as the square root of pulse duration, but were insensitive to variations in surface roughness when the roughness was <25 Å rms. Careful cleaning increased the damage threshold at 3.2 ns by removing particulates.

Key words: BK-7 glass; fused silica; laser damage; polished surfaces; pulse duration dependence of damage; surface roughness.

1. Introduction

The relationship between surface roughness and laser damage thresholds of polished glass surfaces is not well understood. Extreme roughness, rms roughness >100 Å, caused reductions in damage threshold for 1064-nm pulses of 40 ns [1] and 0.15 ns [2] durations. For relatively smooth surfaces, rms roughness <40 Å, the correlation between roughness and thresholds held at 40 ns [1], but not at .15 ns [2]. This is but one example of what seems to be a systematic difference in damage induced by short-duration and long-duration pulses [3]. If such systematic variations are real, theories of laser damage must be compatible. The question of surface roughness and its influence on damage thresholds is also of practical importance. If smoother surfaces have higher thresholds, additional polishing will be an easy fix for some laser damage problems. We report here additional measurements of damage thresholds on polished surfaces of varied roughness.

2. Threshold Measurements

Entrance-surface and exit-surface thresholds for laser damage on four glass windows were measured using linearly polarized 1064-nm pulses with durations of 0.17 ns, 1.0 ns, 1.6 ns, and 3.2 ns, incident at 10° from the normal. Two lasers were used to make the measurements. A passively mode-locked Nd:YAG oscillator provided the 0.17-ns pulses. The waveform of each pulse was not recorded except by a fast diode/oscilloscope combination which was adequate to detect improper mode-locking. The assigned pulse width 0.17 ns is the mean pulse width most recently recorded for this laser. This mean is stable. It has varied from 0.15 to 0.17 ns during the last two years. However, the shot to shot variation in pulse widths from passively mode-locked lasers is large, typically ± 30% of the mean. Intensity or optical electric field strength cannot be accurately measured for mode-locked oscillators unless the waveform of each pulse is recorded. Pulses at 1.0 ns, 1.6 ns, and 3.2 ns were obtained by gating a portion from a 30-ns pulse produced by a Nd:YAG oscillator operating in a single cavity mode. The waveform for each pulse was recorded to verify pulse duration.

With both lasers, the beam profile in the sample plane was recorded on each firing, and absolute flux computed to within ± 7%. Beam diameter at the sample was 2-3 mm. Details of this measurement procedure are recorded elsewhere [4].

3. Damage Samples

Three samples, designated A, 081, and C18, were BK-7 glass. Sample A was a $\lambda/20$, 2"-diameter, 3°-wedged window of grade-A material purchased for use in the damage experiment. It had been used for over two years prior to these tests, and frequently cleaned with acetone or alcohol. Details of its preparation are unknown, except that "absorbing" abrassives, i.e., iron oxide, were not used. Sample 081 was carefully prepared from PH-3 grade material for damage testing. It was ground using progressively smaller alumina grit size; at each size the surface was ground to a depth equal to 3 times the previous grit diameter. Final polish was done with commercially available CeO_2. The surface roughness was 10 Å rms [5], which is extremely smooth for conventionally polished BK-7. Sample C18 had one conventionally polished surface, and one surface finished by bowl-feed polishing. Companion samples to C18 exhibited rms roughness of 7-9 Å on the bowl-feed surfaces [5]. CeO_2 was used to polish C18.

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One sample of optical grade fused silica was tested. It was a 2-inch diameter window prepared for use in the damage facility. Polishing history is unknown except that iron-oxide was not used as a polishing agent.

All four samples had surfaces which meet or exceed specifications for usable optical components. Two were typical of conventional polishing, with roughnesses of 20-25 Å; two had carefully prepared surfaces and were somewhat smoother.

4. Results and Conclusions

Damage thresholds for the four samples are shown in figures 1-4. The following conclusions can be drawn.

1. The smoothest BK-7 surfaces did not have the highest thresholds. Samples C18 and 081 were carefully prepared yet had thresholds less than that of the routinely polished surfaces on sample A. Some other variable, probably surface absorption, is more important than surface roughness in setting short-pulse thresholds on surfaces with roughness <30-40 Å.

2. Contamination by particulates can lower thresholds at 3.2 ns by as much as 50%. The first experiments on sample A yielded low thresholds. The sample was scrubbed with soap and water, alcohol, and acetone, and retested. Surface scatter was reduced and thresholds increased as shown in figure 1. Scrubbing did not change thresholds on new samples C18 and 081.

3. Thresholds scaled approximately as the square root of pulse duration [6]. Departure from this scaling law was greatest on the surface with the lowest threshold, the rear surface of C18. For that sample thresholds at 1.6 and 3.2 ns were nominally the same.

4. Exit-surface thresholds were less than entrance-surface thresholds, although the ratio was not always as predicted [7] by the ratio of intensities at exit and entrance surfaces,

$$\frac{I_{exit}}{I_{ent.}} = \frac{4n^2}{(n+1)^2}.$$

5. Acknowledgments

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6. References

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7. Figures

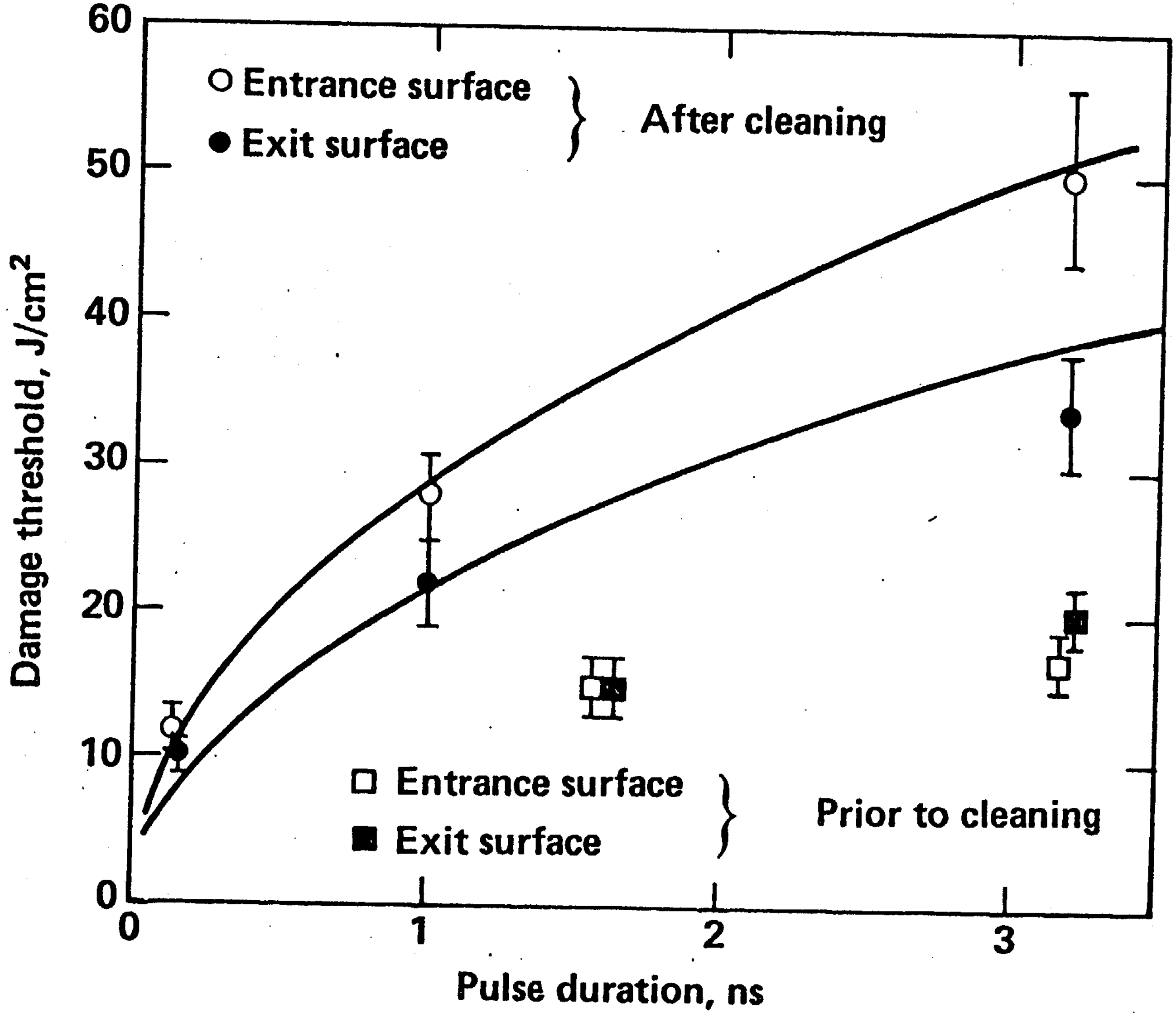
Fig. 1. Surface damage threshold vs. pulse duration, BK-7 sample A. Data indicated by squares was taken prior to a vigorous scrub cleaning. This sample had been used as a splitter prior to these tests. The accumulated particulates could not be removed by less than scrubbing. Curves are best-fit square-root functions.

Fig. 2. Surface damage threshold vs. pulse duration, BK-7 sample 081. Curves are best-fit square root functions.

Fig. 3. Surface damage thresholds vs. pulse duration, BK-7 sample C18. This sample was not large enough to allow measurement at all four pulse durations. Curves are best-fit square root functions.

Fig. 4. Surface damage threshold vs. pulse duration, polished fused silica. Curve is a best-fit (to exit surface data) square root function. The error in entrance surface threshold at 3.2 ns is due to site to site variations in the surface, and exceeds the $\pm$ 7% uncertainty in flux measurements.

BARE BK-7 SAMPLE A



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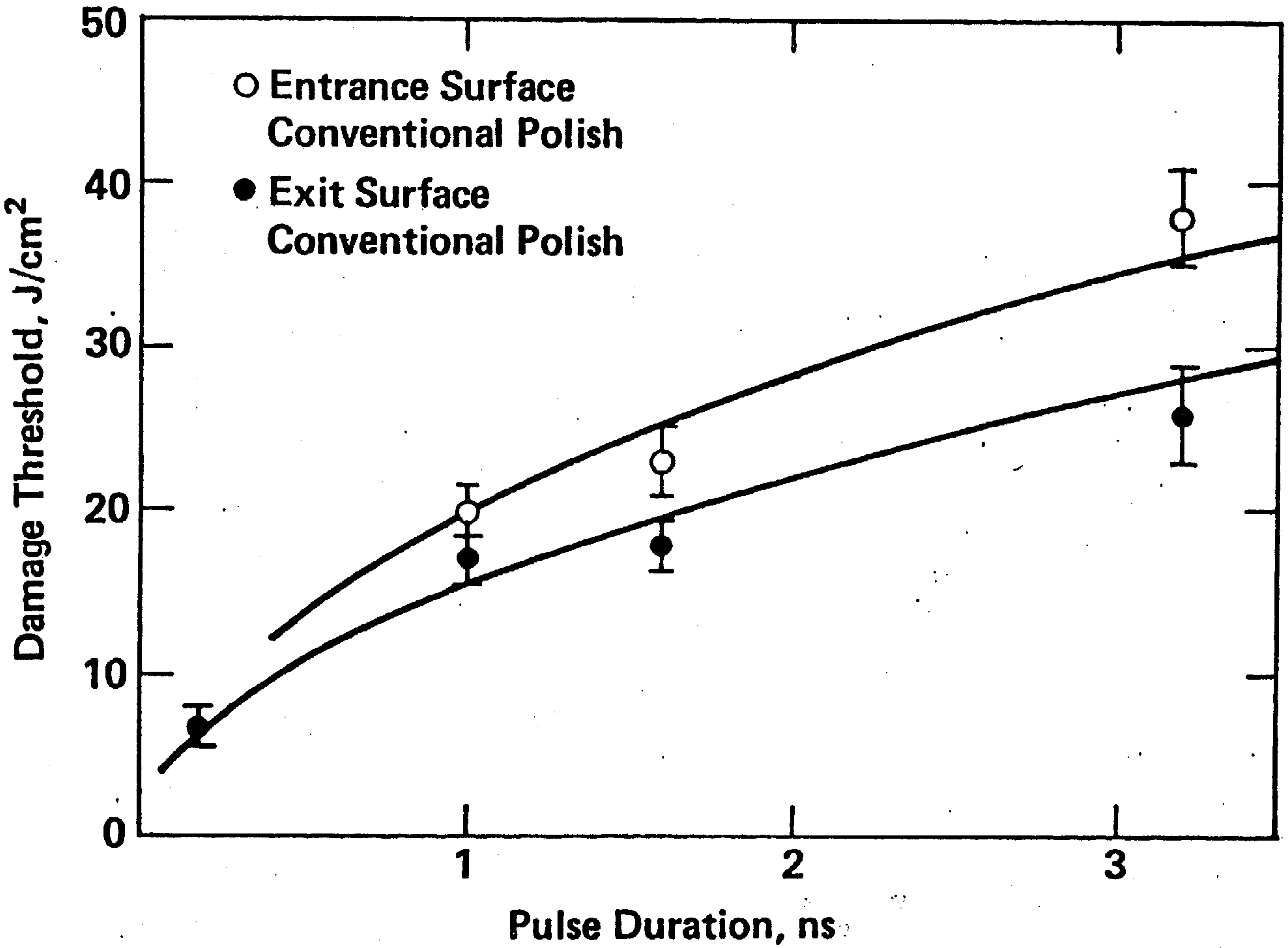
BARE BK-7 SAMPLE 081



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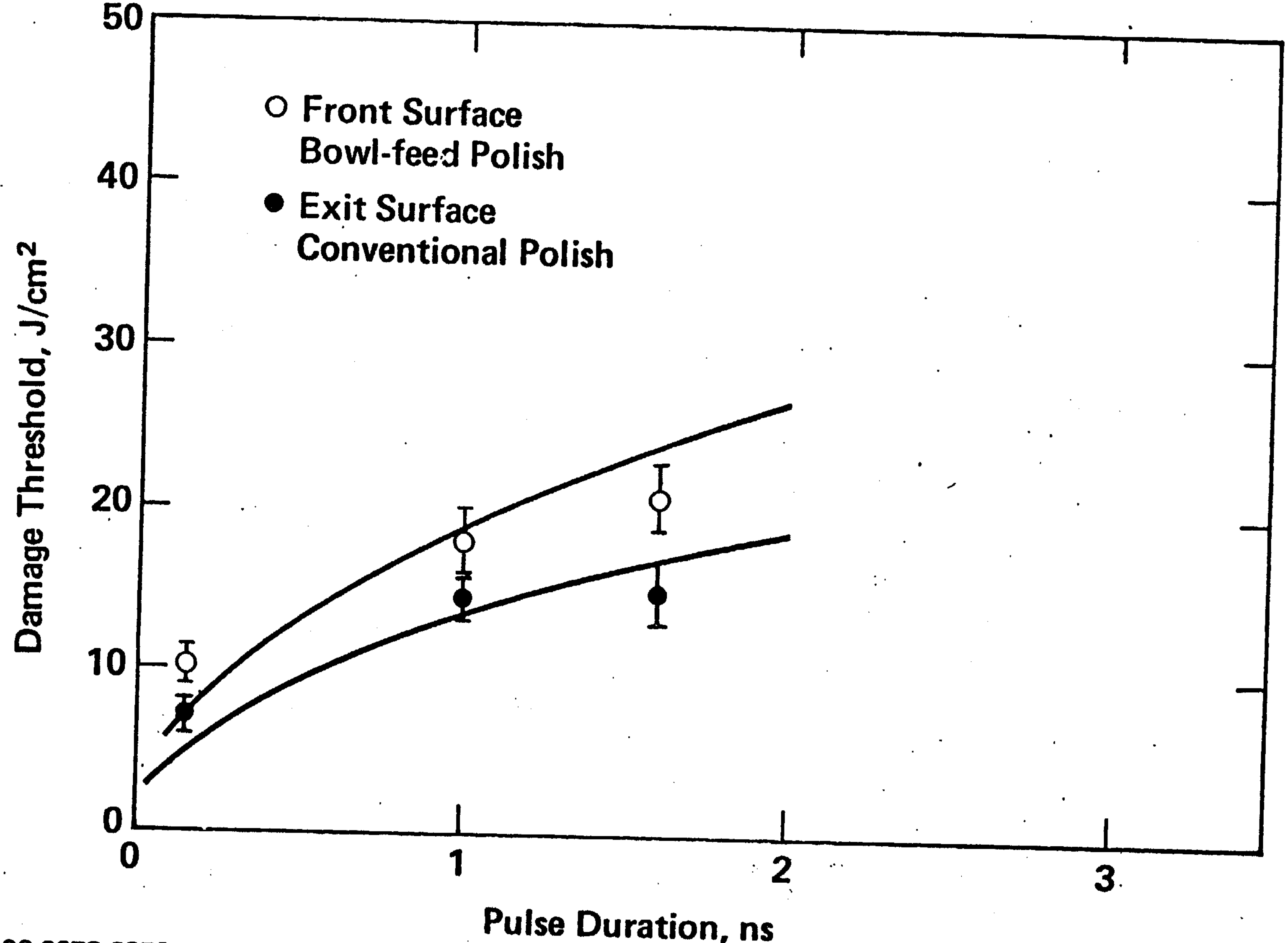
BARE BK-7 SAMPLE C18



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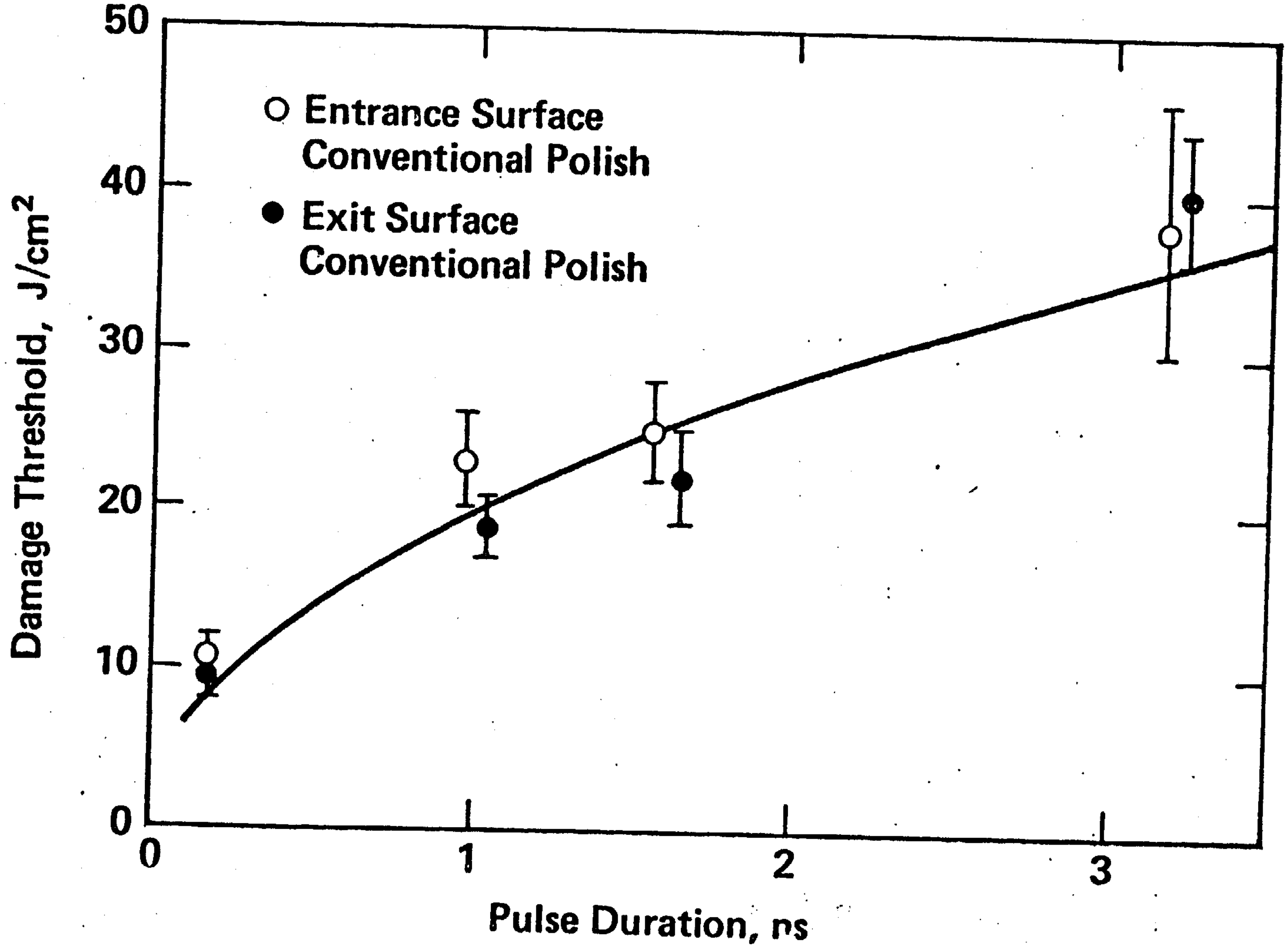

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Fig. 4.